Wearable Encounter-Type Haptic Device with 2-DoF Motion and Vibration for Presentation of Friction

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ABSTRACT

In haptic interaction, friction caused by slip on the fingertip is a key factor for manual manipulation as well as exploration of texture and shape. From the moment of contact, the friction contains vertical and tangential skin deformations and vibrations, not all of which have been simultaneously supported by previous portable/wearable haptic devices. We propose a portable haptic device that has the ability to present skin deformation and vibration with two degrees of freedom by using two types of motors: a voice coil motor (VCM) for vertical motion and vibration, and direct current motors for tangential skin stretch. The VCM also achieves encounter-type haptic interactions. A combination of these motions encompasses most cutaneous cues for realistic friction.

Keywords: encounter type, friction, haptic device, wearable.

Index Terms: H.5.2 [Information interfaces and presentation]: User interfaces —Haptic I/O

1 INTRODUCTION

In haptic interaction, friction caused by slip on the fingertip is known to be a key factor in capacities such as manual manipulation and exploration of texture or shape. However, the presentation of friction with wearable/portable devices has not been fully realized. In this paper, we develop a novel haptic device to present realistic friction. The device achieves (1) vertical motion, (2) vertical vibration, (3) encounter-type presentation, and (4) horizontal skin stretch, by combining two types of actuators that move vertically and tangentially.

Although friction consists of force and cutaneous sensation, we focused on cutaneous sensation to develop a portable device. Cutaneous cues from the moment of contact with an object can be divided into four elements (Figure 1:). The first two are skin deformations caused by tangential and vertical resistances that occur when a finger sticks on a surface (low-frequency component). The latter two are vibrations caused by either finger contact or sliding the finger on the surface (high-frequency component). We need to consider how to present these four elements for the realistic rendering of frictional sensation.

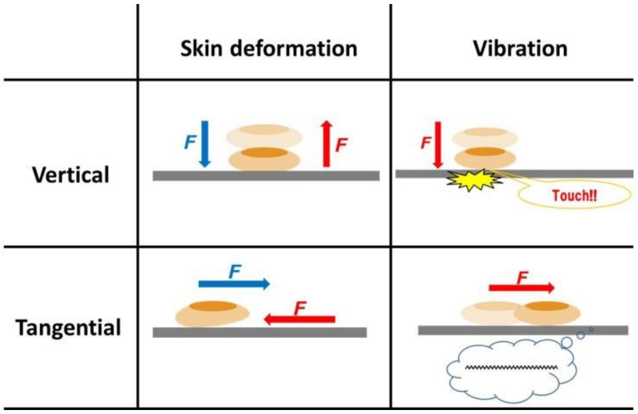

Figure 1: Components of frictional sensation. Top left, Vertical resistance; Top right, Vibration from surface when a finger touches a surface; Bottom left, Tangential resistance; Bottom left, Tangential vibration

In some previous studies, wearable tactile devices that present skin deformation primarily for the presentation of a pseudo force sensation have been developed. Minamizawa et al. developed the Gravity Grabber, which is a finger-mounted device with two DC motors and a belt. The belt fastens the finger to present vertical deformation and moves horizontally to present tangential deformation of the skin [1]. They succeeded in representing the weight of the virtual contents picked by two fingers. Massimiliano et al. also developed a haptic device to present the low-frequency component of friction, which can generate skin stretch with a light setup [2]. They used a shape memory alloy to move a tactor on a two-dimensional surface.

To present vibration, many portable devices have achieved the representation of contact or texture feeling. CyberTouch [3] is a commercially available wearable device that realizes the presentation of vibration to each finger, mainly focusing on the sensation of touch. Konyo et al. succeeded in presenting the high-frequency component of friction by using ICPF actuators [4]. They confirmed that the grasping force is affected by presenting subthreshold vibration.

Whereas the frequency range and degrees of freedom are separately covered in these studies, all four components in Figure 1 have not been achieved simultaneously in a portable form. Although we are unable to distinguish vibration directions, we require at least three: horizontal deformation, vertical deformation, and vibration. For example, in stick-slip, a typical frictional phenomenon, high-frequency vibration occurs following skin deformation. This shows that combinational presentation of skin deformation and vibration is indispensable for the representation of friction.

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Furthermore, previous studies on wearable devices share a common feature in that tactile sensation is always present while the device is worn. Fujita et al. and Bicchi et al. found that the skin contact area influences the feeling of softness [5][6]. The contact area also influences physical friction [7]. These facts imply that in the case of friction, in addition to the contact area, the act of touching the surface itself may be a cue for friction perception.

There have been some studies on “encounter-type” haptic displays [9][9]. In this type of display, the end effector moves and contacts the skin. The high-frequency component of the contact can be easily achieved because the collision is physical. Whereas the encounter-type device tends to be complex, Nakagawara et al. have developed an encounter-type master hand [10]. Although it can present contact itself, it is unsuitable for presenting friction because the movement is limited to the vertical direction. Sylvester et al. have reported that tangential skin displacement is a key element for presenting friction [11].

1.1 Proposed method

On the basis of these discussions, we developped a haptic device that presents tangential skin stretch and contact conditions with encounter-type actuation.

Figure 1: shows a schematic diagram of our method. The device is composed of one voice coil motor (VCM), two DC motors, and a belt. Coordinated actuation of the two types of actuators facilitates vertical and tangential movement of the belt. Although the dual DC motor setup was adopted in the Gravity Grabber [1] and the device for softness sensation [12], our system also allows for contact between finger and contactor, and high-frequency vibration is almost directly presented by the VCM through the film.

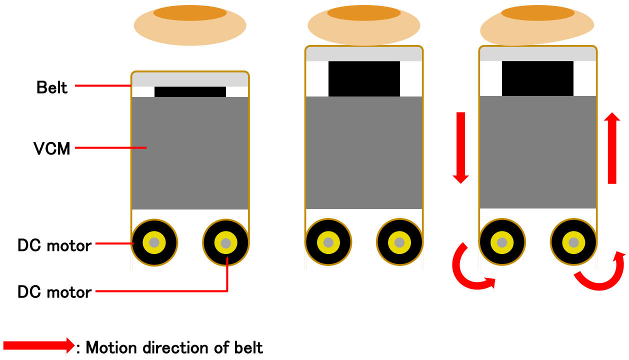

Figure 2: Principle of proposed device. Left, No touch condition; Center, Touch condition; Right, Presentation of skin deformation

2 DEVICE

Figure 3: shows an overview of our device and Figure 4: shows the system structure. It consists of a VCM (LA08-10-000A, BEI Kimco Magnetics) to present vertical displacement, collision with a surface, and vibration, as well as two DC motors with 1:4.1 planetary gear head (RE13, maxon motor) with polyimide film (Kapton100H, DU PONT-TORAY Co., Ltd.) for tangential skin stretch. Shafts of DC motors are extended for attaching the film. Two rotary sensors (RDC506002A, ALPS Electric Co., Ltd.) are used to measure the rotation angle, which gives the horizontal and vertical displacement of the film. We also used four photo reflectors (SG-105, KODENSHI Co., Ltd) and walls covered with retro-reflective sheet to measure the position of the device. All sensing data are sent to a microcontroller (mbed, NCP LPC 1768, NXP Semiconductors).

Our encounter-type presentation requires a very fast measurement–presentation loop. For example, while the device freely moves on air, the VCM must be controlled to represent a static surface. Therefore, common methods of position measurement such as by using a camera are unsuitable. We put the device into a box (286 mm × 260 mm × 147 mm), the inner walls of which were covered in retro-reflective sheet (9201, Ref-Lite Co., Ltd). Each of the four photo reflectors measures the distance between the device and a wall of the box. The retro-reflective sheets elongate the sensing distance of the photo reflectors owing to their specific reflective characteristics. The VCM and the DC motors are actuated according to this position information. Therefore, the main control loop is strictly confined to the microcontroller, which facilitates a fast feedback loop. Although these measurement principles have been used to sense wind velocity by measuring the movement of a panel [13], to the best of our knowledge, this technique is rarely adopted for a haptic interface.

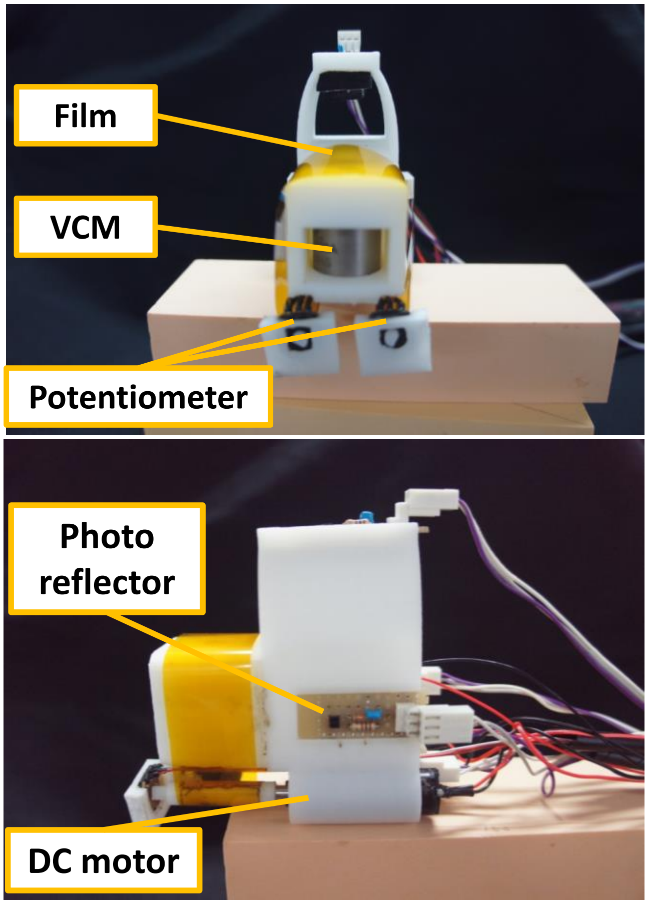

Figure 3: Front and side views of the device

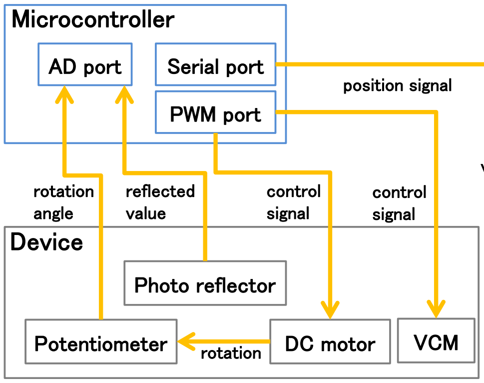

Figure 4: System structure

Figure 5: Overview of device use

In this system, we realized haptic interaction with a virtual surface. The device works together with a virtual finger in a PC monitor. The VCM is actuated according to vertical position information from the microcontroller, and touches the actual finger when the virtual finger contacts the surface. If the device is moved tangentially, DC motors wind the film and skin is stretched (Figure 5:).

3 EXPERIMENT 1

We conducted an experiment to verify the accuracy of our position-sensing method.

We placed the device at the left end of the box and obtained ten measurements of the difference in voltage between the left and right photo reflectors. We repeated the measurement in 1-cm steps until reaching the right end. Overview of the experiment is shown in Figure 6:.

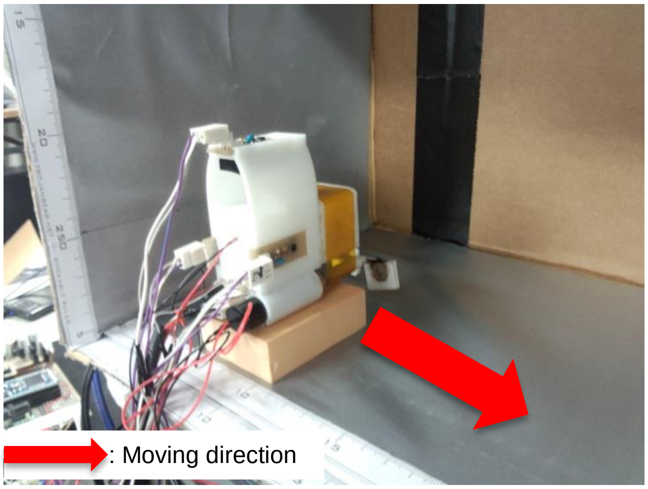

Figure 6: Overview of the experiment

The result is shown in Figure 7:. The horizontal axis represents the position of the device from the left end, and the vertical axis shows the voltage difference between the left and right photo reflectors. All data at every measurement point are in the range of ±0.015 V from the average value, which is equivalent to 0.8 mm at the center of the box and 0.4 mm at both ends of the measured positions. Therefore, we can obtain the position of the device with an accuracy of less than 1 mm by our method, which is appropriate for rough surface presentation but not perfectly sufficient for small texture presentation.

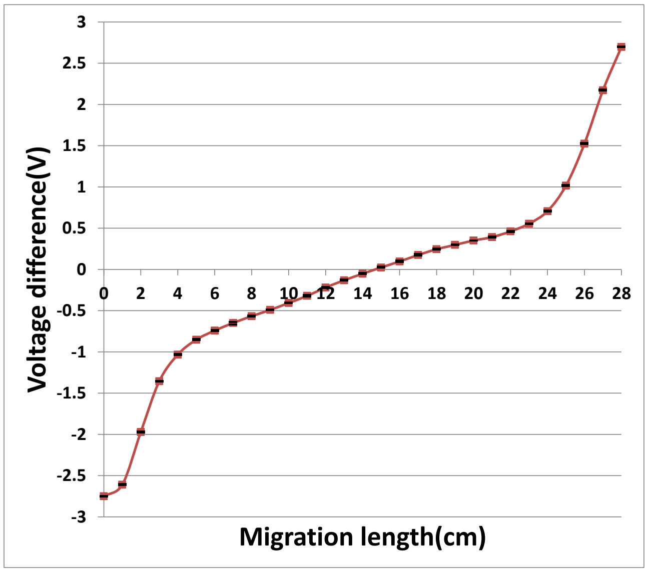

Figure 7: Sensor evaluation results.

4 CONTROL EVALUATION

We evaluated the response of the horizontal displacement response of the film that is actuated by DC motors. A simple PD control was employed. To prevent stack of film, pre-tension was applied regularly by actuating both DC motors. The travel distance of the film was measured by rotary sensor attached to the DC motor. We placed an index finger on the film, with about 50 g pressure, and measured step response with destination se to 5mm, which is an appropriate value for skin deformation.

The result is shown in Figure 8:. The horizontal axis means times, and the vertical axis represents the rolled value of the film. According to this graph, we confirmed that the film reached its destination 40ms after giving command position, which is appropriate for presenting low frequency deformation.

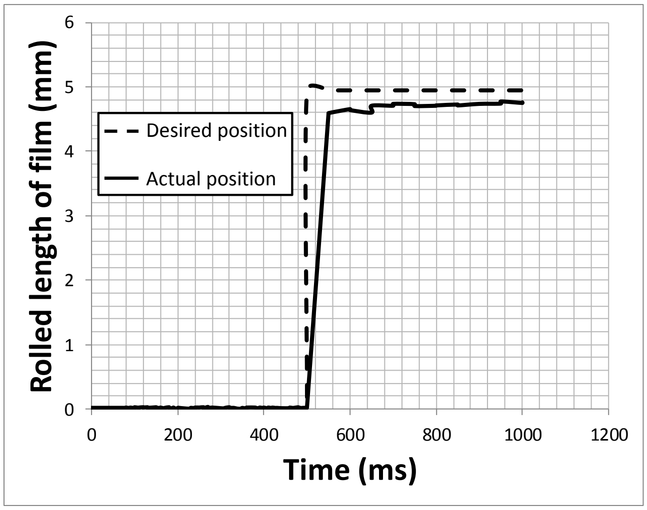

Figure 8: Step response of the film

5 CONCLUSION

In this study, we developed a wearable encounter-type haptic device to present friction. The device could present horizontal and vertical deformation of the skin, high-frequency vibration, and contact information by an encounter-type mechanism. The system employed a fast optical position-sensing method with a simple setup, using photo reflectors and retro-reflective sheets. Two basic evaluations confirmed sufficient accuracy of the sensing method and sufficient speed of horizontal displacement.

Future work will address verification of device controllability, rendering of the frictional phenomenon known as stick-slip, and evaluation of the rendered sensations.

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